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# "The Circulation and Characteristics of Weddell and Ross Sea Ice"

by

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Interim Progress Report  
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RADARSAT ADRO Investigation

**“The Circulation and Characteristics of Weddell and Ross Sea Ice”**

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**Objective**

The purpose of this study is to develop techniques for extracting sea-ice characteristics from satellite microwave data acquired over the Southern Ocean, and in particular in the Weddell and Ross Seas. Gridded parameters, including ice velocity, divergence, and area of new ice formation will be ultimately generated from RADARSAT data. Products will be used as inputs to fine-resolution regional model estimates of surface fluxes of heat, salt, freshwater and momentum, such that the thermohaline circulation forcing ocean ventilation, water mass formation and ocean-atmosphere interactions can be calculated.

**Progress to Date**

To-date, preparation for wide-swath RADARSAT images have been made, by using ERS synthetic aperture radar (SAR) and Scatterometer images to document the annual cycle of Antarctic sea-ice growth and decay together with its interannual variability. For this purpose, we ordered combined ERS-1/2 radar observations, thereby monitoring formation and decay of the Antarctic sea ice cover over the 1991 - 1996 period. These measurements comprise ERS AMI SAR and Scatterometer data, the latter (low-bit-rate) enabling continuous monitoring during periods when snap-shot SAR images are unavailable.

3-day spaced ERS-1 Scatterometer images have been tracked to test the techniques proposed for Antarctic Radarsat data. Gridded ice motion fields have been produced for the entire 1992 year and are presently being validated and tested against ERS-1 SAR motion vectors and buoy information. Field data collected in 1992, provide meteorological, oceanographic information; and shipborne scatterometer measurements enable validation of these products and help prepare for wide-swath hh-pol ScanSAR images.

SAR products from the early 1992 drift period of Ice Station Weddell and the Winter Weddell Gyre Study are being analysed together with these fields in conjunction with an existing model to validate dynamic and thermodynamic model predictions and to test schemes for assimilation of these measurements in flux calculations. Using a coupled regional model and two-dimensional model (in collaboration with Martin Kreyscher of the AWI), we have made preliminary estimates of the magnitude of the surface fluxes and documented variability in heat fluxes and determined the role of sea-ice in driving seasonal to interannual variability in bottom water production in the Weddell Sea.

## **Scientific Results**

### **SAR**

Ice-tracking algorithms have allowed ice to be successfully tracked and monitored in several regions of intensive shipborne field experiments. The recent 1994 Anzflux experiment has been extremely important for documenting growth and decay of sea ice in an extremely dynamic ice margin environment with high ocean heat fluxes, during a reappearance of the Weddell Polynya. These results will be the subject of a future publication. Two studies combining 1992 SAR data and field experiment surface measurements are presently being concluded, describing processes controlling radar backscattering from Antarctic sea ice under periods of distinctive thermodynamic change. Results are contained in papers submitted for publication to the Journal of Geophysical Research.

New SAR data from planned RADARSAT acquisitions (see following section on data requests) will allow sea-ice tracking in different locations and different seasons to be undertaken, to test high resolution kinematics retrievals in various seasons. Unfortunately, an Antarctic SAR time-series does not yet exist since the ERS-1 mission began in 1991. This is a serious concern for seasonal-interannual changes to be successfully tracked. A special effort must be made to make this goal a priority within the lifetime of the RADARSAT satellites. See section on concerns.

Results from SAR ice kinematics retrievals are enabling momentum balance formulations to be tested under varying ice conditions, and to enable prognostic models relating ice divergence and wind stress to be developed. This will ultimately enable wind-stress measurements to be used in ice models as a proxy for satellite observations of ice divergence and open water production. Regions of open water within the ice pack are precisely those which enable vigorous fluxes of heat from ocean to atmosphere. Similarly, these regions are the focus for water mass production and salinity-driven vertical and horizontal circulations.

### **Scatterometer**

In the continuing application of ERS-1/2 C-band scatterometer data for studying large-scale characteristics of the Antarctic sea ice, we evaluated the image-enhancement technique from the perspective of problems in the assumptions of azimuthal isotropy and stationarity of the targets. Azimuthal modulation characteristics of Antarctic sea ice. ERS-1/2 AMI scatterometer mode data from several study regions in the Antarctic seasonal sea-ice pack were evaluated for azimuthal

modulation. When appropriate, the incidence-angle dependence was estimated and removed in a study region before determining if azimuthal modulation is present in the data. Other comparisons are made using the fore and aft beam measurement difference. Results demonstrate that over the ice pack, azimuthal modulation of the radar backscatter is predominantly less than 1 dB at the scale of observation of the ERS-1 C- band scatterometer.

The consistency of the analysis methods used in the sea-ice azimuth study was established by comparing sea ice results with land ice-sheet results. Using the same methodologies for both land and sea ice, while azimuthal modulation was shown to be negligible in the sea-ice regions studied, land ice study regions exhibited significant azimuthal modulation consistent with the results of previous studies of azimuthal modulation over land ice sheets. Areas in the Marginal Ice Zone (MIZ), where long wavelength swell waves can penetrate deep into the ice pack, also displayed measurable levels of azimuthal modulation in the ERS-1 scatterometer measurements due largely to the ice pack being broken up into small randomly oriented ice floes of varying shapes and sizes which ride on the long-wavelength wave trains.

Recent developments include the development of a capability to track ice motion in enhanced-resolution Scatterometer images (Figure 1). Scatterometer motion products will be used to monitor large-scale ice mass fluxes around Antarctica, and primarily to record source and sink regions of freshwater. Large-scale motion products are essential to monitoring seasonal to interannual variations in ice production and freshwater flux, and the balance of the two are essential to the salt balance in enclosed basins such as the Weddell Sea, where changes in this balance will lead to ocean instability, reduced sea-ice concentration, and a significant impact on the global climate.

### **Data Acquisition Requests (DARs) and Datasets Ordered To-date**

Data acquisition requests (DARs) have been largely planned for ERS-2, in the absence of RADARSAT data. Recent submission of two DARs plan for ScanSAR acquisition of summer ice minimum images in the Ross and Amundsen Sea, and in the western Weddell Sea. Winter '97 DARs will follow up with acquisitions of winter ice maximum data in both regions.

#### **Submitted RADARSAT DARs**

##### ***RADARSAT***

Two DARs have been placed for repeat acquisition of summer ice data during ice minimum. These data acquisitions will comprise twice weekly imaging of the region of perennial ice which survives summer melt in the Ross-Amundsen basin and the western Weddell Sea. Figure 2 shows the regions of interest which will be imaged by RADARSAT ScanSAR mode.

##### ***ERS-1/2***

Data acquisition requests were submitted for phase F ERS-1 data, which will be used for sea-ice mapping and motion tracking in the western Weddell Sea during austral summer in 1994/95 and in summer 1995/96. Future ERS-2 data will be acquired at McMurdo receiving station to monitor Ross and Amundsen Sea seasonal ice growth and decay.

#### Ordered ERS-1/2 radar data

Two existing sets of SAR data have been ordered to date: (a) phase E SAR data which will be used for ice mapping and ice motion tracking in the vicinity of “AnZone” Experiment, in the Eastern Weddell Sea. Derived ERS-1 scatterometer data products from JPL are being used for the scatterometer imaging portion of this study. Data for the years 1992-present day are currently under analysis.

### **Future Plans**

In the next year, techniques will be tested and evaluated using Radarsat SAR data, over both the Weddell and Ross Seas. The approach is; (a) production and gridding of geophysical products from the McMurdo and tape-recorded Radarsat data, (b) ice tracking and derivation of estimates of net opening and closing of the ice pack, and (c) use of these data together with empirical or existing regional models for surface flux estimates. The model will produce estimates of surface heat and salt fluxes, and be used to make statements regarding the importance of the Weddell and Ross Seas upon regional production of Antarctic Bottom Water.

Measurements of ice motion from 100 km SAR image pairs and scatterometer images will be combined with weather analysis fields, to map rates of ice drift and open water production. When merged with gridded air temperature and wind speed information from European Centre for Medium Range Weather Forecasting (ECMWF) analysis fields, these measurements will be used in estimates of the regional energy budget using coupled ice-ocean-atmosphere models.

Future plans are to use ScanSAR data in localised regions to validate large-scale ice-motion products (see Figure 1). SAR is, however, still required to quantify the area covered by small leads in the ice - and to measure small-scale divergence in persistent polynya regions. Future regionally focused studies will utilise SAR measurements in coastal polynya regions to monitor ice formation and motion processes in key regions for production of tracer water masses.

During January-March 1997 a visit by Douglas Low (SPRI) to JPL will enable quantification of the effects of summer melt progression on Weddell Sea perennial ice. Results will enable statements regarding the connection between protracted warming on the Antarctic peninsula, and recent appearance of meltponding in this region. Interannual variability in the melt signal will be studied with respect to timing of the melt season and its extent.

### **Concerns**

We still do not have a complete, uninterrupted seasonal cycle of sea-ice growth and decay anywhere in Antarctica from SAR, since ERS-1 was first placed in orbit. With respect to learning about the connectivity between seasonal-interannual fluctuations in Antarctic sea-ice extent (and characteristics) and climate, we are not able to satisfy the requirement to collect SAR image data at times of critical importance, unless for instance RADARSAT tape recorder time is secured over the Weddell Sea. A complete cycle of sea-ice coverage is required in the Southern Ocean. This is a principal requirement of this study in both the Weddell and Ross Seas.

ERS-1 and ERS-2 SAR can, at best, only be used to provide sea-ice sampling of opportunity, and further work will lay more emphasis on the development of scatterometer imaging using ERS-1 data. Doppler positioning enables higher resolution images to be generated from NSCAT than is currently possible with ERS-1 scatterometer data. It enables full-polar scatterometer imaging to ~12 km resolution with ~4km pixel spacing. However, RADARSAT remains as the only 100m resolution dataset with which to characterise the small-scale dynamics of the ice cover, at short timescales of 1 week or less.

## **Recent Publications**

Drinkwater, M.R., Satellite Microwave Radar Observations of Antarctic Sea Ice. In C. Tsatsoulis and R. Kwok (Eds.), *Recent Advances in the Analysis of SAR for Remote Sensing of the Polar Oceans*, Springer Verlag, New York, In Press.

Drinkwater, M.R., Active Microwave Radar Observations of Weddell Sea Ice, *AGU Antarctic Research Series*, In Press.

Drinkwater, M.R., and V.I. Lytle, ERS-1 SAR and Field-Observed Characteristics of Austral Fall Freeze-up in the Weddell Sea, Antarctica, In Press *J. Geophys. Res.*

Early, D. S., and D.G. Long, Azimuth Modulation of C-band Scatterometer  $\sigma^0$  Over Southern Ocean Sea Ice, In Press *IEEE Transactions on Geoscience and Remote Sensing*.

Figure 1. ERS-1 Scatterometer enhanced resolution image of Antarctica, showing ice-motion displacement vectors in the Weddell and Ross Seas, retrieved from ice-tracking between this and a subsequent image, spaced at an interval of 9 days. Base image shows ice extent during winter ice advance.

Figure 2. Location of RADARSAT Data Acquisition Request (DAR) polygons for measurements of 1996/97 austral summer perennial ice regions.